Supply chain sustainability in VUCA: role of BCT-driven SC mapping and 'Visiceability'

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Abstract

The study investigates the role of three essential supply chain capabilities: visibility, traceability, and mapping, collectivity termed as 'visiceability', in the relationship between blockchain technology and supply chain sustainability. The study focuses on Malaysia's Electronics Component manufacturing firms, a sub-sector of the electrical and electronics (E&E) industry. Data were collected from 105 through a close-ended questionnaire. PLS-SEM was employed to examine the modeled relationships. The findings of the study challenge the notion that supply chain (SC) traceability alone is responsible for mediating the impact of blockchain technology (BCT) on SC sustainability. However, findings confirm the significant roles of SC Mapping and Visibility in the association between BCT and SC sustainability. Findings further validate the significant impact of blockchain technology (BCT) on supply chain (SC) sustainability, highlighting its multifaceted role. The findings suggest that firms can build their intermediary capabilities instead of exclusively focusing on adopting BCT for SC sustainability. These capabilities can further channel the impact of BCT on improving SC Sustainable. Our findings illustrate that BCT can enhance SC visibility by offering a precise and transparent record of the products, inventory, and transactions. Hence, we strongly suggest that managers consider leveraging BCT to improve their SC visibility, thereby uplifting the sustainability of a supply.

Keywords: SC Mapping; Visibility; Traceability; Blockchain technology; SC Sustainability

1. Introduction

Recent devastating calamities, extreme climatic events, and natural disasters underscore the urgency to intensify the efforts toward sustainability (Hussain et al., 2020). These events have created a compelling call for businesses and societies to adopt sustainable production and consumption patterns to preserve the well-being of future generations (Ahmed et al., 2021; Islam et al., 2021; Kusi-Sarpong et al., 2022). COP-27 has reiterated this warning, and leaders around the globe have agreed to aggressively work on the digital and sustainable future of the world. In this perspective, business leaders are expected to play their part by transforming their end-to-end supply chains toward sustainability parameters and practices. Adopting a sustainable supply chain can help firms mitigate adverse socio-environmental impacts on their business processes. (Kusi-Sarpong et al., 2019). For example, sustainable supply chain practices can significantly reduce the carbon emission of a firm, emitting from its supply chain operations (Kusi-Sarpong et al., 2016; Khan, Ali, & Zaman, 2022). Furthermore, SC sustainability can help a firm to adopt green transportation systems and renewable energy sources (Sahebi, Mosayebi, Masoomi, & Marandi, 2022), which can have positive environmental effects. SC sustainability also promotes cutting-edge green product design and service, environmentally friendly waste management, green packaging, and preserve natural resources as well as biodiversity; all can aid in mitigating climate change and other environmental issues and concerns (Nayal et al., 2022; Sliva & Palsson 2022)

Practitioners and researchers stress the need for supply chain visibility and traceability– *co-termed as 'visiceability'*—to adopt sustainable supply chain practices. Especially, the actual impacts of technology adoption in terms of sustainability cannot be attained without having SC *'visiceability'*. For example, Park & Li, (2021) denoted that BCT adoption improves the visibility and traceability of supply chain processes, further improving SC sustainability. Likewise, Mangla, Kazançoğlu, Yıldızbaşı, Öztürk, & Çalık (2022)demonstrate that without attaining transparency and visibility in SC processes, a firm cannot reap the true benefits of technology adoption. Their findings are supported by various research (e.g., Bai, Quayson, & Sarkis 2022; Erol, Ar, & Peker 2022; Yousefi & Tosarkani 2023). One of the significant works in this context is of Khan, Mubarik, et al. (2022). They contend that BCT does not directly contribute to the SC sustainability of firms. Rather, BCT improves the SC visibility of a firm, thereby enhancing its sustainability. Studies also indicate that SC traceability enables tracking all supply chain processes (Al-Khatib, 2023; Funlade Sunmola et al., 2023). For example, Zhou, Pullman, & Xu (2022) argued an instrumental role of SC traceability in routing the impact of BCT on SC sustainability. A review of the studies highlights the ambiguity in the literature on the direct role of BCT in SC sustainability. These ambiguities necessitate the need to re-examine the direct impact of BCT on SC sustainability. Likewise, it also requires investigating the role of SC traceability and visibility in the association between BCT and SC sustainability. This leads us to draw the first research question of the study:

RQ1: What is the impact of BCT on the SC sustainability of a firm?

Recently few researchers (Choi et al., 2020; Mubarik et al. 2021; Ali et al.,2021; Kusi-sarpong et al.,2022) identified SC mapping as a crucial element in achieving sustainability. Thus, BCT can help a firm effectively map its SC processes (SC mapping), further improving its SC sustainability (Mubarik et al., 2021). SC mapping process identifies environmental, social, and governance risks throughout the supply chain, enabling companies to improve their SC sustainability (Mubarik et al., 2022). It is, however, clear from the preceding discussion that there are a lot of studies that have been conducted in contributing to saving the environment for future generations, such as barriers to BCT for aiding SC sustainability, integrating SC visibility within the supply chains, introducing SC mapping into the supply chains, implementing SC traceability in the supply chains among others. Yet, there remains a research gap in investigating the indirect impact of BCT on SC sustainability through SC visibility, SC traceability, and SC mapping.

Additionally, despite the significant amount of work conducted on SC sustainability, there still exist unanswered questions on how SC sustainability can be improved. Especially in the context of digital and green, there is an intriguing question as to whether pursuing both requires a separate set of resources or complementary. Blockchain technology can play a groundbreaking role in improving SC sustainability and visibility owing to its salient features. This sets out the second research question of the study:

RQ2: What role does SC visibility play in the association between BCT and SC sustainability?

To address the two major research questions mentioned above, we collected data from 105 firms belonging to the Malaysian Electronic Component industry, a Malaysian Electrical and Electronic sector sub-sector, to empirically investigate the above research questions. This sector is considered one of the most significant contributors to the global production of electronic components. It is presently in the limelight due to its immense impact on the supply chain of many other products.

The rest of this study is organized as follows. Section 2 discusses the literature and hypotheses covering supply chain sustainability, visibility, mapping, traceability, blockchain technology, and hypotheses development. Section 3 presents the population and sampling methodology, the data collection instrument, and the analytical method. The results are presented in section 4, covering respondent's demographic, the reliability and validity of the constructs, hypotheses testing, and multi-group analysis. Section 5 presents the discussion of the results, whereas the discussion of the implications is presented in Section 6. Section 7 presents the conclusion and future research directions.

2. Literature review and hypotheses development

2.1 Definitions and Dimensions

2.1.1 Supply Chain Sustainability

Although the concept of sustainability gained recognition and popularity through the Brundtland Report (1987) and the efforts of the World Commission on Environment and Development, its roots can be traced back to the 18th century (Balsalobre-Lorente et al., 2021; Almi & Boumar, 2023; Kirkby, O'Keefe, & Timberlake, 2023; Ogryzek, 2023; Park & Li, 2021; Torán-Pereg et al., 2023). SC sustainability encompasses all activities that reduce carbon footprints and improve ecological, environmental, and social conditions (Islam et al., 2021; Men, Yaqub, Yan, Irfan, & Haider, 2023; Sachin & Rajesh, 2022). Further, it can also be elaborated as adopting sustainable practices across the supply chain (Khan, Mubarik et al., 2022). Over time, the definition has augmented to include a broader range of factors, such as economic and social variables (Chege & Wang, 2020; Hysa, Kruja, Rehman, & Laurenti, 2020). The notion of SC sustainability includes a firm's environmental, social, and economic sustainability. It addresses issues such as fair labor laws, human rights, ethical business practices, and resource conservation of raw materials. In its current definition, SC sustainability refers to managing environmental, social, and economic factors that affect the product and service life cycle while maximizing value to stakeholders and minimizing negative impacts (Khan et al., 2021; Arda, Montabon, Tatoglu, Golgeci, & Zaim, 2023).

2.1.2 Supply Chain Visibility

SC visibility (SCV) surfaced in the early 80s to track shipments and inventories using technologies like RFID, barcodes, etc. (Davies & Wang, 2021). It is also referred to as the tracking and monitoring of products, information, and financial flows across the entire supply chain. SC visibility concept centers on locating products' identity and transit status within and outside the supply chain (Roy, 2021). With time, the definition of SC visibility has evolved. It is a necessary part of SSCM by offering a comprehensive view, aiding businesses in enhancing efficiency, cutting costs, and increasing customer satisfaction (Mubarik, Mazmi and Zaman 2021). SC visibility is known as a supply chain attribute that allows tracking of all supply chain stages, from procuring raw materials to delivering finished goods to customers (Al-Khatib, 2023; Funlade Sunmola et al., 2023). SC visibility also can be defined as the real-time tracking and monitoring of goods and services, including the identity, location, and status of entities involved, along with planned and actual dates and times for events that can contribute to improving the performance of collaboration and credibility in supply chains (Baah, Opoku Agyeman, et al., 2022; Rogerson & Parry, 2020).

2.1.3 Supply Chain Mapping

SC mapping is the process of documenting and visualizing the supply chain processes, relationships, and flows across a firm's supply chain. It includes identifying and understanding the interconnected and interdependent network of upstream, downstream, and midstream supply chains. In other words, SC mapping involves the real-time or near real-time visualization of the supply chain from suppliers to customers. SC mapping necessitates extending supply chain visualization and documentation beyond the tier 1 suppliers and customers (Mubarik et al., 2021; Mubarik, Kusi-Sarpong, Govindan, Khan, & Oyedijo, 2023). SC mapping was first adopted in 1980s in response to the increasing complexity of supply chains (Khan, Mubarik, et al., 2022). However, the concept has evolved, transcending various supply-chain operations. Today, SC mapping enables businesses to visualize their supply chain networks, including goods, services, and information flow. It also helps the organization connect components such as operations, stakeholders, resources, and geographical features to ensure that product and information movement can be tracked across all supply chain stages (Mubarik et al., 2023). The importance of comprehending the entire supply chain, from raw materials to finished goods, as well as the interdependencies between different stakeholders and processes, is emphasized in the current definitions of SC mapping. SC mapping uses cutting-edge tools like BCT, machine learning, and data analytics to collect, process, and provide insights for better decision-making (Olan, Liu, Suklan, Jayawickrama, & Arakpogun, 2022).

2.1.4 Supply chain traceability

SC traceability refers to the ability of a firm to track and monitor the flow of goods, materials, and components across the supply chain from the place of origin to consumption (Li et al., 2023). It also involves tracking and capturing information about various stages, entities, and supply chain processes. In recent years, its importance has grown due to the demand for accountability and transparency in global supply chains (Schmidt & Moreno, 2022). According to current definitions, SC traceability refers to the end-to-end traceability of the real-time flow of goods, materials, and components (Razak et al., 2021). This is one of the significant organizational capabilities that can help make the right decision at the right time (Song, Sung, & Park, 2019). Adoption of industry standards and best practices is also required to ensure consistency and interoperability across supply chain networks. Ultimately, SC traceability is considered a critical tool for improving supply chain resilience, mitigating risk, and driving long-term growth (Bateman, 2015).

2.1.5 Blockchain technology

Unlike conventional systems, blockchain technology uses a decentralized database and records transactions on an immutable digital ledger. It is considered a transparent, temper-free and immutable system if executing and recording transactions (F Dietrich, Louw, & Palm, 2023; Nakamoto, 2008; Ramazhamba & Venter, 2023). BCT consists of a chain of blocks with timestamps, a cryptographic hash of the immediately previous block, and transactional information that cannot be amended or deleted without consensus from the participants of the supply chain (Amico & Cigolini, 2023; Balon, Kalinowski, & Paprocka, 2023; Kaur, Kaur, & Sood, 2023; Rahman et al., 2023). Although BCT was initially introduced for the finance sector, it quickly captivated the attention of supply chain professionals (Oudani, Sebbar, Zkik, El Harraki, & Belhadi, 2023). Presently, various big organizations have adopted BCT for managing their supply chains. BCT has also evolved to encompass a variety of applications, including tracking and tracing products, verifying authenticity, and reducing fraud (Dujak & Sajter, 2019). Modern definitions of BCT in supply chain management highlight the need for integration and standardization throughout the supply chain since it utilizes smart contracts and other advanced technologies to automate processes and streamline transactions (Saddikuti, Galwankar, & Akilesh Sai, 2023).

2.2 Hypothesis development

2.2.1 Impact of BCT on SC Sustainability

BCT has many applications in the supply chain that can make it more sustainable (Chang, El-Rayes, & Shi, 2022). For instance, BCT can be used to track and verify the sustainability credentials of products with its feature of traceability and transparency (i.e., certifications for organic, fair trade, carbon-neutral production, etc.). Again, BCT's security system enables supply chain partners to share sustainability data securely (Xie, Zheng, He, Wei, & Hu, 2023), which promotes collaboration and alignment on sustainability goals. Moreover, BCT can share waste management policies, amount of carbon emission, and natural resource consumption among its supply chain partners. This can allow us to monitor each other contribution to achieve SC sustainability and identify the process which can be improved or optimized. In addition, BCT allows companies to monitor product lifecycle, which can facilitate sustainable business model development (Yontar, 2023). Also, in a study of the Agri-supply chain, Mukherjee, Singh, Mishra, & Bag (2021) stated that BCT can make the supply chain sustainable with its modern features. Similarly, Paliwal, Chandra, & Sharma (2020) also mentioned that SC sustainability could be achievable with the help of BCT. Again, Bai, Cordeiro, & Sarkis (2022) acknowledged that BCT could contribute to achieving SC sustainability. Further, a case study by Khanfar, Iranmanesh, Ghobakhloo, Senali, & Fathi (2021) presented numerous BCTs applications for manufacturing which can facilitate SC sustainability. Moreover, it also may be required to cross-check supply chain members to ensure that they are adhering to the sustainability policy, detecting fraud and misinformation, mitigating future risks, securing data, and so on. Additionally, documentation costs and time must be reduced. BCT can provide solutions for these things as a whole with its numerous features such as transparency, accountability, data sharing policy, etc. (Chang et al., 2022; Oguntegbe, Di Paola, & Vona, 2022; Treiblmaier & Garaus, 2023). However, the above discussion makes it clear that BCT establish SC sustainability.

H1. BCT enhances a company's SC sustainability.

2.2.2 Mediating Role of SC Mapping

Impact of BCT on SC mapping

A significant advantage of using BCT in the supply chain is that it can improve SC mapping and positively impact SC visibility and sustainability (Kusi-Sarpong, Mubarik, Khan, Brown, & Mubarak, 2022).BCT mainly provides a decentralized and visible platform with a record of every change in the supply chain, and this help to map the supply chain. Again, integrating BCT and SC mapping can improve bottlenecks, risk management, interoperability, process improvements, etc. (Kavasidis, Lallas, Gerogiannis, & Karageorgos, 2022). Indeed, the use of Blockchain for supply chain mapping is relatively new and emerging (Rawal, Manogaran, & Poongodi, 2022). There is limited consensus on how the potential benefits of BCT can be effectively utilized . Some studies have explored the use of Blockchain for particular aspects of supply chain mapping, such as tracking products or verifying documents, and found a positive relationship (Saleh, Ghazali, & Rana, 2020). For example, a case study on the fish supply chain in Thailand discovered that BCT makes the SC mapping process effective (Tsolakis, Schumacher, Dora, & Kumar, 2022). SC mapping is becoming highly significant to address continual improvement needs and broader shifts that are reshaping the global economy and influencing global trade due to the pandemic which leads SC sustainability (MacCarthy, Ahmed, & Demirel, 2022). One of the main benefits of SC mapping is for upstream, midstream, and downstream SC mapping (Mubarik et al., 2023). However, above discussion proved that BCT has the capability to transform this method into a digital one thanks to its features, particularly tracking, sharing, distributed ledger, etc. (Alikhani, Ranjbar, Jamali, Torabi, & Zobel, 2023).

H2a. BCT positively influences SC mapping

Impact of the SC Mapping on SC Sustainability

A review of the literature reveals the multifaceted impact of SC mapping on sustainability. For example, Mubarik et al.,(2023) argue that SC mapping can assist a firm in identifying the sustainability-related risks and vulnerabilities in its supply chain processes and can help to mitigate them. SC mapping can also help companiesidentify the processes that can be optimized in the supply chain to reduce waste, energy consumption, and emissions (Nandi, Sarkis, Hervani, & Helms, 2021). For example, reducing transportation distance can assist with cost reductions while lowering carbon emissions. It is also possible to use SC mapping as a tool in the life cycle assessment of a company's product, and this can push the supply chain toward sustainability (M. Xu et al., 2019). SC mapping can also help measure a product's environmental impact, from raw material to end-of-life disposal. As a consequence, companies move towards achieving environmental sustainability. Moreover, mapping the supply chain can expose the sustainability performance of the parties involved in the supply chain and encourage them to practice sustainability (Khan, Mubarik, et al., 2022).

On the other hand, companies can identify areas where they are not compliant with sustainability regulations and take corrective actions. It also facilitates companies to monitor their development over time and share their sustainability performance with stakeholders. SC mapping can help companies identify innovation opportunities in sustainable practices to develop or improve sustainable products (Kusi-Sarpong et al., 2022). In addition, SC mapping can enable transparency throughout the supply chain to understand the sustainability impact of the products. Further, de Sousa Jabbour et al. (2020) revealed that companies could improve their ability to identify and address sustainability issues such as green sourcing, waste reduction, and environmental impact by creating a detailed map of the different phases and stakeholders involved in the supply chain. Despite the significant discussion on the impact of SC mapping on sustainability, its adoption is shallow. This can be partly attributed to the lack of concrete empirical studies examining the impact of SC mapping on sustainability. The above backdrop leads us to hypothesize as follows:

H2b. SC mapping can have a positive influence on SC sustainability

H2a and H2b combinedly test the following hypothesis.

Hypothesis 2: SC mapping mediates the relationship between BCT and SC Sustainability.

2.2.3 Mediating Role of SC Visibility

Impact of BCT on SC Visibility

Regarding SC visibility, BCT can share real-time visibility of every transaction of funds and the movements of goods in the supply chain to manage the supply chain efficiently (Guo, Chen, Li, Li, & Lu, 2022). This system also ensures SC visibility by transferring secure, auditable, and transparent data of the overall supply chain to reduce the risks of fraud and errors (Treiblmaier & Garaus, 2023). Additionally, BCT can digitalize the supply chain by increasing data accuracy and data exchange speed. It also allows the companies to check whether their partners comply with the regulations and maintain the commitment. It can facilitate digital twins in the supply chain to enhance SC visibility by simulating any tests or products to the customers (Liu et al., 2023). It will increase not only customer satisfaction but also trust.

Furthermore, research suggests that SC visibility could be improved by incorporating BCT into the supply chains (Brookbanks & Parry, 2022). For instance, Trautmann, Hübner, & Lasch (2022) found that BCT can help increase SC visibility to combat drug counterfeiting. The focus of their research was the pharmaceutical sector.

BCT can reduce risks such as being duped by false information (Alkhudary, Queiroz, & Féniès, 2022). Moreover, BCT can produce an accurate and transparent record of the products, inventory, and transactions, enhancing SC visibility (Haleem, Javaid, Singh, Suman, & Rab, 2021; J. Xu, Guo, Xie, & Yan, 2020). However, the information above indicated that a revolution in SC visibility could be achieved through BCT to increase transparency, efficiency, and sustainability (F. T. Sunmola, 2021; F Sunmola & Apeji, 2020).

H3a. BCT positively influences SC visibility

Impact of SC Visibility on SC Sustainability

SC visibility can help companies optimize their supply chain operations, reduce waste, and increase productivity by providing real-time track records of inventory levels, shipping times, and delivery schedules to achieve SC sustainability (Apeji & Sunmola, 2022). This will also aid companies in identifying areas where they can streamline their operations and cut costs which directly impact the economic attribute of SC sustainability. Additionally, Dubey et al. (2020) found a positive impact on the SC sustainability performance of focal companies. Also, SC visibility enables data-driven decision-making in the sustainable SC process since it can collect the data of entire supply chain operations (Al-Khatib, 2023). Furthermore, supply chain disruptions (i.e., natural disasters, trade disputes, or supplier bankruptcies) can have a significant impact on a company's bottom line, which can disrupt the sustainability of the supply chain (Asortse & Denga, 2023; Eldem et al., 2022), and it is possible to identify as well as mitigate risks (for example, identifying alternative suppliers or adjusting production schedules) by ensuring SC visibility in the supply chain.

Moreover, SC visibility builds the relationships among supply chain members, which can help to improve the social aspects of SC sustainability (Baah, Acquah, & Ofori, 2022). For instance, sharing accurate and up-to-date information about orders and delivery schedules can assist businesses in building strong relationships with their suppliers. Recently, customers are also concerned about the sustainability and ethical practices of the companies from which they purchase goods (Dedunu & Sedara, 2023). As a result of SC visibility, companies can provide a real-time view of orders, potential delays, and actual locations to their customers as well as represent their ethical and environmental commitments and contributions. It is also found that, SC visibility promotes greater collaboration in the business which can make the supply chain more sustainable since it will expose the contribution of each member towards achieving SC sustainability (Brun, Karaosman, & Barresi, 2020).

H3b. SC visibility leads to increase SC sustainability.

H3a and H3b combinedly test the following hypothesis.

Hypothesis 3: SC visibility mediates the relationship between BCT and SC Sustainability.

2.4 Mediating Role of SC Traceability

Impact of BCT on SC Traceability

BCT provides a decentralized, secure way to share, track, and verify transaction records, making SC traceability more credible (Jena & Dash, 2021; Wang, Zheng, Jiang, & Tang, 2021). Centobelli, Cerchione, Vecchio, Oropallo, & Secundo (2022) mentioned that BCT could impact SC traceability, particularly as a quick and efficient means of exchanging information between parties. It can also simplify the process by creating a shared database of information that all participants can access and verify, which can assist SC traceability. Moreover, using smart contracts, BCT can automate many supply chain management processes (Habib et al., 2020), such as inventory tracking, order fulfillment, and payment processing, impacting SC traceability. In addition, BCT is a promising technology for SC traceability, according to Biswas, Jalali, Ansaripoor, & De Giovanni (2023), as it can guarantee traceability throughout the supply chain and reduce risks like the sharing of falsified data. However, numerous studies on BCT and supply chains have demonstrated both BCT's direct and indirect impact on SC traceability. For instance, Westerkamp, Victor, & Küpper suggested a BCT model for the manufacturing process 2018 and discovered that it could handle complex processes with robust SC traceability. Again, Mirabelli & Solina (2020) tried to review the literature on BCT-based SC traceability for agriculture. Their findings indicate that BCT is still in its infancy but is favorable for SC traceability. Another attempt at reviewing the literature on how BCT enabled SC traceability was made by Dasaklis, Voutsinas, Tsoulfas, & Casino (2022). Their conclusions indicate that BCT holds great promise for SC traceability.

H4a. BCT has a positive impact on SC traceability

Impact of SC Traceability on SC Sustainability

SC traceability can help to identify and address sustainability issues such as environmental impacts, social responsibility, ethical sourcing, etc., as well as can create a positive impact on SC sustainability by providing transparency and visibility throughout the supply chain (Kamble, Gunasekaran, & Sharma, 2020; Kashmanian, 2017; Schmidt & Moreno, 2022). As evidence, Agyabeng-Mensah et al. surveyed 274 managers from Ghana's manufacturing industries in 2021 to determine the role of green logistics and SC traceability on sustainability performance, and their findings divulged that SC traceability aggrandizes the performance of sustainable logistics management, which can improve the overall sustainability of supply chains. In addition, food SC traceability has become a global sociological concern due to rising quality and risk concerns. For this, Zhou et al. (2022) sought to contribute to resolving this issue by examining the performance of 450 Chinese firms with SC traceability. They found that SC traceability has a significant impact on sustainability. Further, SC traceability systems can help companies to track the origin and flow of goods and raw materials (Ahmed & MacCarthy, 2021), preventing environmental deterioration and safeguarding biodiversity (Neumann et al., 2018). In addition, the social sustainability of supply chains is directly impacted by labor abuses and human rights violations (Fernando, Halili, Tseng, Tseng, & Lim, 2022; Yu, Xu, Huo, Zhang, & Cao, 2023), which can be found and addressed with the aid of SC traceability (Chen, 2022). Moreover, a study on coffee's supply chain León-Bravo, Ciccullo, & Caniato (2022) found a positive correlation between traceability and SC sustainability. Overall, integrating SC traceability can be an important step toward achieving greater SC sustainability.

H4b. SC traceability has a positive impact on SC sustainability.

H4a and H4b combinedly test the following hypothesis.

Hypothesis 4: SC traceability mediates the relationship between BCT and SC Sustainability.

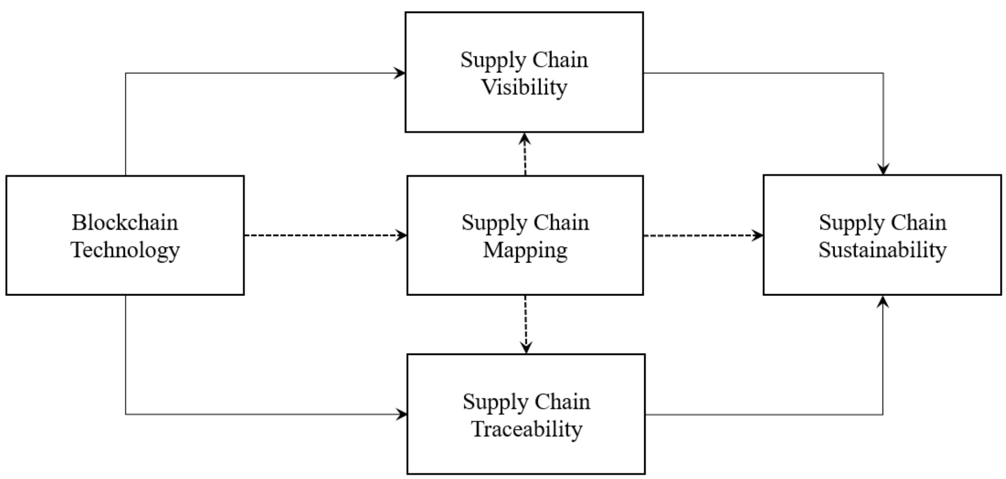

Figure 1: Conceptual Framework

3. Methodology

3.1 Population and Sampling

The study focuses on Malaysia's Electrical and Electronic Sector, one of the largest contributors to Global E&E exports. The sector started with eight companies in 1970, and became one of the largest in a few decades. During 2020, the sector's contribution to Malaysian export was 39.4%. The sector recorded an impressive growth of 30 percent in 2022. The sector is divided into four major sub-sectors: electric components, industrial electronics, consumer electronics, and electrical products. This study focused on the electric component sub-sector, and data were collected from 103 firms operating in this sector located across Malaysia.

3.2 Data Collection Instrument

We have adopted the 07 items construct of BCT from the studies of Cottril (2018) and Gupta (2017). The measure of SC mapping has been adopted from Mubarik et al., (2021). It has 03 sub-constructs and total 25 items. Further, the measure of SC Sustainability has been adopted from Gouda and Saranga (2018), having nine items. The construct of SC visibility has been adopted from Williams et al., (2013). It has three sub-constructs with 20 items. Lastly, the SC traceability construct has been adopted from Kahsmania, which has a total of 05 items (see Table 1). All the constructs have been measured on the 05 Likert scale *(1 from very low to 5 very high).*

Table 1: Constructs and Sources

Construct	Sub-construct	Items	Sources
Blockchain Technology	-	7	Cottril 2018 & Gupta, 2017
Supply Chain Mapping	3	25	Mubarik et al.,(2021)
Supply Chain Sustainability	3	9	Gouda and Saranga (2018)
Supply Chain Visibility	3	20	Williams et al., (2013)
Supply Chain Traceability	-	5	Kashmania (2017)

3.3 Analytical Method

We employed PLS-SEM to examine the hypothesized relationships. The approach is applied in two steps: Reliability and Validity of constructs and hypotheses. PLS-SEM is preferred over other approaches because it handles non-normal data. Likewise, this approach is also proffered for its robustness with a low to moderate sample size.

4. Results

4.1 Respondent's demography

As explained in Section 3.1, the study focuses on the electronic component sub-sector of Malaysia's Electrical and Electronic industry. We targeted 200 firms from Malaysia's five major geographical areas: Penang, Selangor Valley, Johor Baru, KL, and Teranganu, with the help of a third-party data collection firm. Among the approached firms, 113 responded, and after review of the filled questionnaire,08 were excluded due to incompleteness. Hence, 105 firms' data were processed for the analysis. Table 2 exhibits a brief demography of the respondent's firms. Among 105 respondents' firms, 58 are medium-sized, whereas 47 are large-size firms—according to the Malaysian NDSC (*National SME Development Council), firms with an employment size between 75 to 200 are considered medium-sized. In contrast, those with an employment size greater than 200 are categorized as large firms.* Most firms (66%) are older than 15 years old. Around 50% of the employees, who responded on behalf of their firms, hold the manager designation or above.

Table 2 Respondents' Demography

Size (Based on employment)		
Medium*	58	55%
Large**	47	45%
Years in operation		

5 to 10	14	13%
11 to 15	25	24%
16 to 20	37	35%
21 or more	29	28%
Respondent Employees Demography		
Dy General Manager	11	10%
Seniro Manager	19	18%
Manager	23	22%
Dy Manager	25	24%
Asst Manager	21	20%
SC Partner	6	6%

,& show the employment size between 75 to 200 and >200 (Source: National SME Development Council (NSDC).*

4.2 Reliability and Validity of the Constructs

The results of the reliability and validity tests are exhibited in Table 3. The reliability of a construct measures its stability and dependability. The value of CB alpha, and CR are checked to confirm the reliability of a construct. All the constructs are reliable if the values are greater than 0.70 (Hair etal.,2016; Mubarik et al., 2020; Mubarik et al.,2022; Khan et al., 2022). The CR and CB aloha value, exhibited in Table 3, are greater than 0.70, thus confirming that all the constructs are reliable, stable, and dependable. The validity of the constructs is ascertained from two aspects: convergent and discriminant. Convergent validity, at the item level, reflects the extent to which various items of a construct are consistent. It is measured using the values of average variance extracted (AVE), which should be equal to or more than 0.50. The values of AVE in Table 3 for all the constructs are greater than 0.50, thus confirming the convergent validity of all the constructs. Discriminant validity of the constructs, at the item level, shows how much each item of a construct differs from others. It is gauged using HTMT values, which should be less than .90 for a construct to be discriminately valid. HTMT values of all constructs, exhibited in Table 4, are less than 0.90, confirming the DV of all constructs. The reliability and validity test results show each construct's individuality and uni-dimensionality and allow proceeding for the hypotheses testing.

Table 3: Reliability, Validity and Model Fitness

Construct	Sub-Dimensions	ML*	Deleted**	AVE	Sqrt_AVE	CR	CB alpha
Supply Chain Mapping	Upstream mapping	0.71	*SCMp1, SCMp3*	0.51	0.71	0.81	0.77
	Midstream mapping	0.74	*SCMp8*				
	Downstream-mapping	0.76	*SCMp11*				
Supply Chain Sustainability	Environmental Sustainability	0.72	*ES1*	0.53	0.73	0.86	0.83
	Social Sustainability	0.74	*SS4*				
	Supplier Sustainability Development	0.81	*SD3*				
Supply Chain Visibility	-	0.73	*SCI1*	0.55	0.74	0.91	0.72
SC Traceability	-	0.65	*SCT3*	0.52	0.72	0.82	0.81
Block Chain Technologies	-	0.6	*Nil*	0.51	0.71	0.9	0.72

** Minimum loadings*

***Items Deleted having loading below the minimum level*

Table 4: Discriminant Validity based on Hetrotrait-Monotrait (HTMT)

	BCT	SCS	SCV	SCMp
Blockchain Technology (BCT)				
Supply Chain Sustainability (SCS)	0.455			
Supply Chain Visibility (SCV)	0.572	0.459		
Supply Chain Mapping (SCMp)	0.443	0.529	0.852	
SC Traceability (SCT)	0.342	0.318	0.782	0.442

4.3 Hypotheses Testing

The results of the path analysis are illustrated in Table 5, whereas Table 6 has been developed for the hypotheses testing based on these results. The study has primarily four hypotheses. The first hypothesis of the study tests the direct impact of BCT on SC sustainability. The results in Table 6 support the positive and significant impact of BCT on SC sustainability (*β=0.18, t-value 2.192*). The magnitude of the coefficient value shows a moderate to high impact of BCT. Further, the results show a significant and positive role of SC mapping the association between BCT and SC sustainability (*β=0.156, t-value 2.357*), thus supporting the study's second hypothesis. It confirms that the impact of BCT on SC sustainability is significantly routed through SC mapping. Next, we examine the third hypothesis of the study, which checks the mediating role of SC visibility in the association between BCT and SC sustainability. The results of Beta value (*β=0.123, t-value 3.781*) support the third hypothesis of the study. The results (*β=0.0.082, t-value 1.057*) do not support the fourth hypothesis of the study, thus showing that SC Traceability does not mediate the association between BCT and SC Sustainability. Further, the 0.57 value of R-square, the coefficient of determinations, shows a moderate level of the model, attributing 57% variation in SC sustainability to BCT, SC Mapping, SC Visibility, and SC Traceability. Likewise, the value of Q-square (0.392) shows a moderate predictive relevance of the model.

Table 5: Path Model

Hypotheses	Relationship(s)	Beta(std)	S. E	*t*-value	Decision
	BCT→ Supply Chain Sustainability	0.18	0.110	1.636	Rejected
	BCT→ Supply Chain Visibility	0.38	0.070	5.429	Accepted
	Supply Chain Visibility→ Supply Chain Sustainability	0.41	0.101	4.059	Accepted
	BCT→ Supply Chain Mapping	0.49	0.098	5.000	Accepted
	Supply Chain Mapping → Supply Chain Sustainability	0.25	0.030	8.333	Accepted
	BCT → Supply Chain Traceability	0.51	0.125	4.080	Accepted
	Supply Chain Traceability → Supply Chain Sustainability	0.16	0.078	2.046	Accepted
	Supply Chain Mapping → Supply Chain Visibility	0.29	0.054	5.370	Accepted
	Supply Chain mapping →Supply Chain Traceability	0.41	0.111	3.694	Accepted

** $p < 0.01$, * $p < 0.05$

Note: R^2 (SC Sustainability 0.572).

Q^2 (SCS = 0.392)

Table 6: Hypotheses testing

Hypotheses	Relationship(s)	Beta(std)	S.E	*t*-value	Decision
	Blockchain technology improves SC sustainability	0.180	0.0821	2.192	Accepted
	Supply Chain Visibility mediates the relationship between BCT and SC Sustainability	0.156	0.0661	2.357	Accepted
	Supply Chain Mapping mediates the relationship between BCT and SC Sustainability	0.123	0.0324	3.781	Accepted
	Supply Chain Traceability mediates the relationship between BCT and SC Sustainability	0.082	0.0772	1.057	Rejected
	Supply Chain Mapping improves Supply Chain Visibility	0.29	0.054	5.370	Accepted
	Supply Chain Mapping improves Supply Chain Traceability	0.41	0.111	3.694	Accepted

** $p < 0.01$, * $p < 0.05$

4.4 Multi-Group Analysis

Since data were collected from Medium and Large firms, there is a possibility that results may differ by the size of the organization. To check this, we conducted Multi-Group Analysis (MGA), which helps to determine whether results are stable across groups are not. The results of MGA are exhibited in Table 7 below. The insignificant p-values of H1, H2, H3, and H4 show stable results across large and medium firms.

Table 7: Multi-Group Analysis

Hypotheses		Large	Medium	| M-S |	(WS) p-value	(P) p-value
H1	Blockchain technology improves SC sustainability	0.21	0.18	0.03	0.532	0.518
H2	Supply Chain Visibility mediates the relationship between BCT and SC Sustainability	0.143	0.131	0.012	0.287	0.304
H3	Supply Chain Mapping mediates the relationship between BCT and SC Sustainability	0.164	0.197	-0.033	0.142	0.131
H4	Supply Chain Traceability mediates the relationship between BCT and SC Sustainability	0.071	0.052	0.019	0.222	0.192

WS: Welch-Satterthwait
P: Paramteric

5. Discussions

We examined four major hypotheses wherein the results show a significant positive impact of BCT on SCS, supporting the first hypothesis of the study. These results echo the findings of the previous studies, notably Mubarik et al.,(2022), Mobarik, Rasi and Mubarik (2020), Queiroz, Telles, and Bonilla (2019), Wu et al., (2017), Mackey and Nayyer (2017). Although our results concur with the previous studies, it offers novel insights into the BCT-SCS relationship. Our results show that BCT, helps adopt and integrate more energy-efficient devices and equipment for managing the various supply chain operations. Likewise, it helps optimize key supply chain operations like inventory management and transportation by providing greater flexibility. Based on the findings, we argue that BCT reduces cost and improves efficiency by eliminating the need for intermediaries and streamlining supply chain processes.

Our results of the second hypothesis concur with the findings of Mubarik et al., (2022). It helps in understanding how SC mapping can route the impact of BCT on SC Sustainability. BCT, through its decentralized and immutable record, helps map important information about various supply chain entities and processes (Kusi-Sarpong et al., 2021). It enables various supply chain stakeholders to access up-to-date, relevant information securely and reliably. In this way, BCT promotes SC Mapping, allowing an organization to map its SC processes and securely use the information. The real-time information attained due to SC mapping helps a firm to track the flow of goods and services across the supply chain, and identify and mitigate the wastes in the processes, thus promoting SC sustainability.

Further, our results of the third hypothesis support an instrumental role of SC visibility in the association between BCT and SCC Sustainability. These findings illustrate that BCT improves SC visibility by offering transparent, immutable, and real-time information about the flow of goods and various SC entities involves in it (Kusi-Sarpong et al., 2021). It improves SC visibility in a highly cost-effective manner. Further SC visibility help the firm optimize its supply chain processes to minimize its various wastes. Higher level of SC visibility improves socially sustainable supply chain as well. It offers higher level of transparency regarding labor practices, working conditions, and human rights issues (Khan et al., 2021).

Our empirical findings do not support the mediating role of SC Traceability in the association between BCT and SC Sustainability and appear to be in contrast with the extant literature. For example, Queiroz, Telles, and Bonilla (2019,p.249), "*blockchain technologies have the capacity and flexibility to be applied to different SCM contexts. For instance, tracking and providing visibility through the entire supply chain optimizes the information flow and generates cost reduction "*. By having a closer look, it could be found that the impact of BCT is significant on the SC traceability; however, SC traceability's impact on SC Sustainability is not significant. SC traceability may offer real-time tracking of goods flow across the supply chain, yet firms don't need to use this information to improve their SC Sustainability. Further, SC traceability may not provide a deeper picture of the processes through which the products flow. In the absence of information related to SC processes, it is challenging for the firm to take sustainability measures. Hence, based on the findings, we argue that SC traceability alone may not contribute to SC sustainability. Nonetheless, it can play an effective role when combined with SC visibility, wherein the former helps track the products and later provides a deeper understating of the processes.

6. Implications

The study has some key implications for organizations. The first is the adoption of blockchain technologies for SC sustainability. Although BCT has been under the limelight for a decade at least, the organization's major focus was its adoption to uplift its SC sustainability directly. Some organizations remain successful in this venture; however, several firms reported otherwise. The study offers some useful implications for organizations, especially regarding the adoption and integration of BCT for SC sustainability. While BCT has garnered significant attention of scholars and practitioners for the past decade, the focus of the organizations remained on its direct application in uplifting SC sustainability. Although some of the firms succeeded in this endeavor, various organizations reported contrasting results. Extending the understating of existing literature, our study explains that the real value of BCT can be capitalized on by adopting a multi-faceted approach. We suggest managers focus on developing intermediary capabilities that can effectively channel the impact of BCT on SC sustainability. The present study identifies two such capabilities: SC mapping and SC visibility. Our empirical findings depict that the impact of BCT on SC sustainability can be significant when channeled through SC mapping and visibility. In other words, BCT can improve SC viability by providing transparent and precise information about the various SC processes. Hence, we strongly recommend managers consider BCT adoption for improving SC visibility, which can further contribute to developing a sustainable supply chain.

Likewise, we suggest firms consider BCT for mapping their supply chain processes, which can improve the sustainability of their SC processes. SC mapping can also help improve the SC visibility of the organization. For instance, SC mapping can be used to transparently analyze the costs associated with various supply chain aspects: a major component of SC visibility (Nothacker, 2021). This increases visibility by providing information on the costs of production, transportation, and other activities associated with delivering a finished product to the customer. Moreover, SC mapping can assist SC visibility to plan capacity and demand by providing information on customer demand, inventory level, production capacity, etc. (Ivanov & Dolgui, 2021). It will increase the SC visibility and make it possible to forecast demand and make plans for effectively operating the supply chain. Additionally, SC mapping can compare the supply chain performance against industry standards and best practices. Further, with the help of real-time alerts of SC mapping, it's possible to make SC visibility more credible; upcoming issues related to the supply chain can be detected, such as quality or delays, and stakeholders or managers can take immediate steps to mitigate these. Also, SC mapping can improve collaboration through SC visibility among supply chain stakeholders such as suppliers, manufacturers, distributors, retailers, etc., and track their performance. Adopting BCT for SC sustainability requires developing SC visibility and mapping, which can help an organization capitalize on its actual benefits.

7. Conclusion and Future Research Directions

The study examines the roles of SC visibility, SC Mapping, and SC traceability in the association between BCT and SC sustainability. The hypothesized roles were tested using the data from 105 Electronic component manufacturing firms from Malaysia by applying PLS-SEM. Our results confirm the significant mediating roles of SC visibility and SC mapping in the association between BCT and SC Sustainability. However, our results challenge the findings of extant studies by highlighting an insignificant role of SC traceability in this association. SC traceability may offer real-time tracking of goods flow across the supply chain, yet firms don't need to use this information to improve their SC Sustainability. Further, SC traceability may not provide a deeper picture of the processes through which the products flow. In the absence of information related to SC processes, it is challenging for the firm to take sustainability measures.

Findings on the mediating role of SC visibility illustrate that BCT improves SC visibility by offering transparent, immutable, and real-time information about the flow of goods and various SC entities involves in it. It improves SC visibility in a highly cost-effective manner. Further SC visibility help a firm optimize its supply chain processes to minimize waste. Likewise, BCT promotes SC Mapping, allowing an organization to map its SC processes and securely use the information. The real-time information attained due to SC mapping helps a firm to track the flow of goods and services across the supply chain, and identify and mitigate the wastes in the processes, thus promoting SC sustainability. The impact of BCT on SC sustainability shows that BCT helps adopt and integrate more energy-efficient devices and equipment for managing the various supply chain operations. Likewise, it helps optimize critical supply chain operations like inventory management and transportation by providing greater flexibility. Further, we show that BCT, through its decentralized and immutable record, helps map important information about various supply chain entities and processes. It enables various supply chain stakeholders to access up-to-date, relevant information securely and reliably.

We have some critical directions for future researchers. We will suggest future researchers to take the big data sets, including various industries, to examine the generalizability of the model of this study. Likewise, future researchers can adopt a mixed-method approach to understand better the various relationships, especially the role of SC traceability.

Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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